Chapter 2

THE SOCIO-ECONOMIC IMPACTS OF SPACE INVESTMENTS

The chapter presents three different approaches on how space investments can be associated with socio-economic impacts. An assessment of the types of benefits derived from space programmes are first provided, based on an original international literature review. In addition, new OECD indicators on the growing role of space applications in official development assistance projects (ODA) are presented for the first time. Finally, the growing relevance of space technology transfers and commercialisation for the wider economy is highlighted.

Introduction

Returns from investments in space programmes are not always evident, immediate or sustained over time. But the evidence is growing on the diverse benefits stakeholders in public and private sectors may get in terms of enhanced operations, skilled jobs, and new products and services born from past or more recent space research and development programmes.

Efficiency and productivity gains derived from the use of space applications are also becoming more visible across very diverse sectors of the economy and society, although experiences in estimating impacts vary across countries. From agriculture to energy, from routine surveillance to timing of financial transactions, institutional actors and private companies are increasingly using satellite data and signals. Satellites also play a key role in providing communications infrastructure rapidly to areas which lack ground infrastructure, contributing to link rural and isolated areas with urbanised centres. The types of benefits one can expect still really depends on the way a space programme or project is run.

This chapter provides three original perspectives on how space investments can have socio-economic impacts:

- First, the results of an international literature survey provide a brief review of the types of benefits that have been documented for the past thirty years, when investing in space programmes. It provides the basis for further evaluation and impact assessments of space programmes;
- Second, a focus on the impacts of space technologies in the developing world is provided, with new OECD indicators on the growing role of space applications in selected official development assistance projects (ODA);
- Finally, a brief review of space technology transfers and commercialisation is presented, as investments in selected space missions or larger programmes can find later applications beyond the space sector.

An original overview of the socio-economic impacts of space programmes

Different types of socio-economic evaluations and impact assesments of space investments have been carried out over the years, and the demand for these studies has been growing. This section presents the findings of OECD research on the existing literature of socio-economic benefits in the space sector. It provides new insights and evidence on how space investments have been tracked so far, illustrating the most common benefits identified and on selected economic sectors affected by space-related investments. It also contributes to detecting some gaps in the literature, pointing out some ways forward in future assessments of space investments.

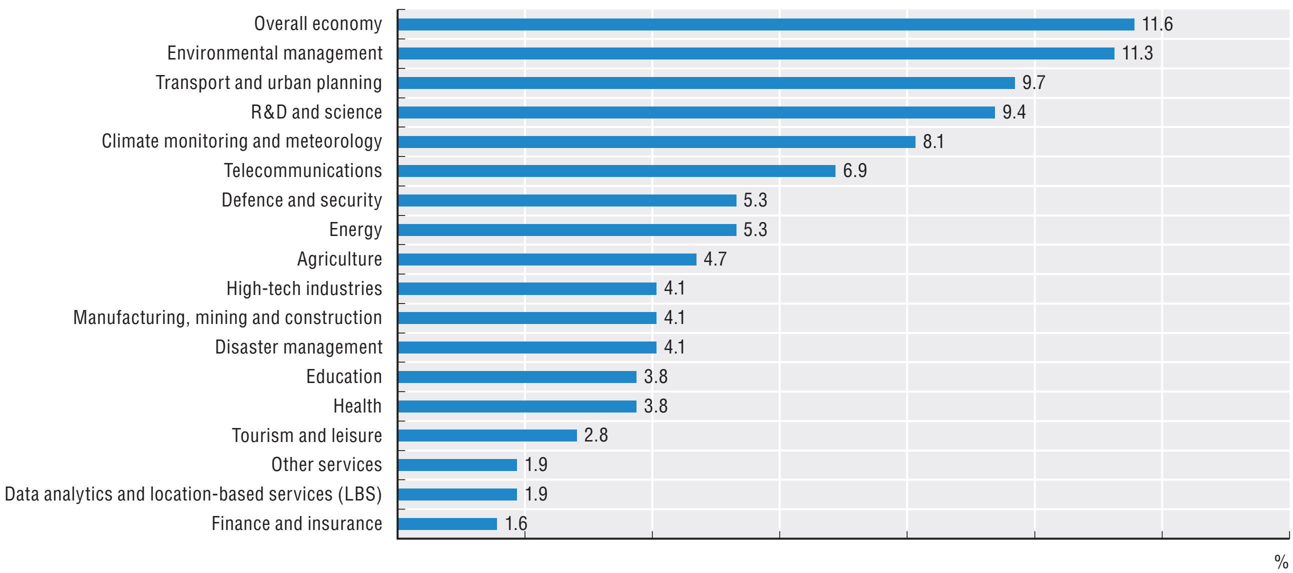
The research is based on a dataset of space-related studies, including 77 publications covering a period ranging from 1972 to 2018. The dataset comprises studies performed internally by space and non-space organisations, as well as academic papers. They include a wide range of studies, analysing national/regional space sectors, space programmes and selected missions. Publications have a wide geographic coverage, analysing the effects of space activities performed at various national, regional and global levels. The largest share of studies focuses on impacts in Europe (22%), in the United States (20%) and more generally at global level (19%). The rest of the studies includes national case studies (e.g. United Kingdom, Canada, the Netherlands, Denmark, Italy and Germany). Very few developing countries are included. Based on this literature review, original indicators were developed after performing a detailed classification of the studies according to the types of benefits and beneficiary sectors.

- In terms of the types of benefits that can be derived from investments in selected programmes, productivity and efficiency gains can often be observed at the firm level (in processes and operations), in the workforce (improvements in workers' skills and know-how) and at the managerial level (organisational benefits such as improved co-ordination and co-operation). Cost savings, cost avoidance, commercial revenues and employment may also occur, in the space sector itself or in other sectors. Depending on data availability, macroeconomic effects of investments can also be tracked, on GDP /value added and tax revenues.
- Beneficiary sectors are the economic sectors that benefit from effects spurred by space activities. As part of the selected categories, they include the overall economy (at national level via GDP); agriculture; health; transport and urban planning; education; environmental management; climate monitoring and meteorology; energy; telecommunications; disaster management; finance and insurance; manufacturing, mining and construction; high-tech industries; defence and security; tourism and leisure; research and development and science; data analytics and location-based services; and other generic services.

With the first institutional investments in large space programmes dating back more than sixty years now, ever-more economic sectors seems to benefit from the socio-economic effects derived from space investments. When examining the literature, several studies assess the impacts of the space sector, of space programmes, or even of the establishment of specific space activities in selected geographic areas, on the local, regional or national economy. More specific studies also analyse benefits of space investments as they spread to sectors such as environmental management, transport and urban planning, R&D and science, climate monitoring and meteorology, and telecommunications. Other sectors include defence and security, energy, and agriculture (Figure 2.1).

Figure 2.1. Selected sectors that benefit from socio-economic effects derived from space investments

Share of total occurrences identified in the literature



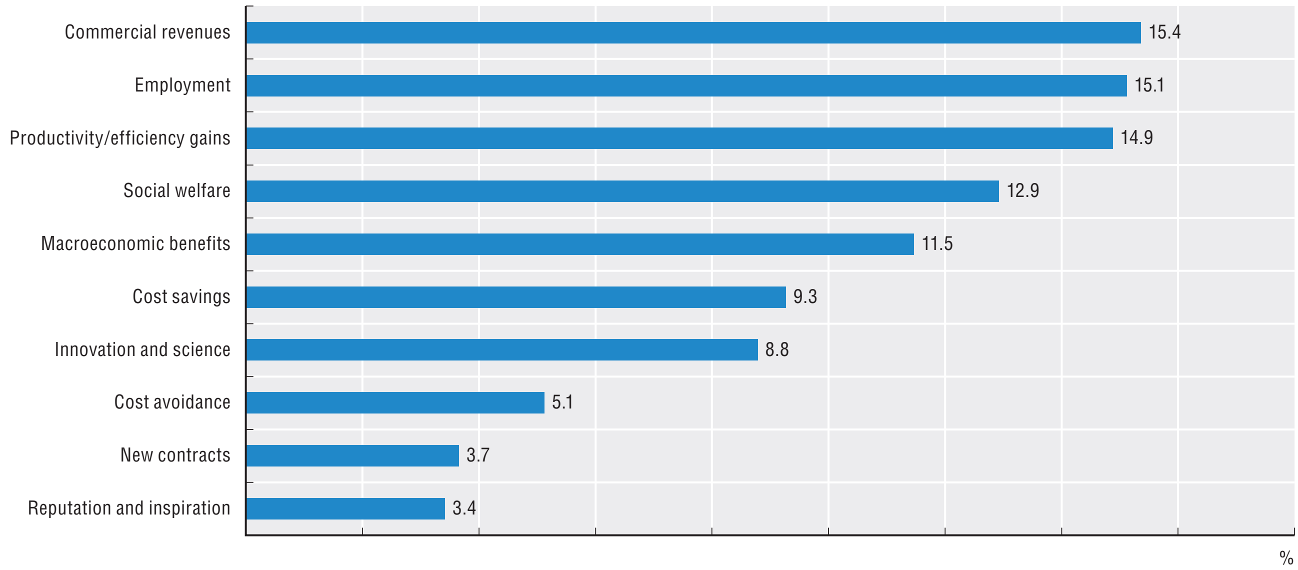
Note: The literature covers 77 impact assessments and programme evaluations published between 1972 and 2018.

In terms of the types of positive effects derived from space investments, commercial revenues represent the top category (Figure 2.2). Several studies found that the implementation of space programmes, technologies or other types of activities created new revenue streams for firms, often beyond the space sector. Commercial revenues are followed by effects on employment, with the creation of new jobs being observed. Productivity and efficiency gains represent another fundamental category of benefits. Many studies assess the socio-economic relevance of space activities at the national, regional or local level, taking a macroeconomic perspective (11.5%), assessing impacts on gross domestic product, value added and additional induced taxation.

The benefits of space do not exclusively impact actors operating in the space sector, as many studies report positive effects in non-space firms and at the broader societal level. This is, for example, the case of cost savings and cost avoidance (Figure 2.3). Around 57% of all cost savings and more than three-quarters of cost avoidance are realised beyond the space sector. Benefits in these categories usually derive from the application of space technologies in other fields, resulting in the reduction of operating costs. Cost avoidance is also highly linked to applications in the context of environmental management, meteorology and disaster management, see also Chapter 7, for example. There, the quality of information provided, often based on satellite data, makes it possible to improve forecasts and decision-making, preventing economic or social costs and losses. On the other hand, positive impacts of space investments on commercial revenues and employment occur more frequently in space firms. Around 59% of effects on revenues and 71% of those on job creation have been quantified in the space sector.

Figure 2.2. Types of positive effects derived from space investments

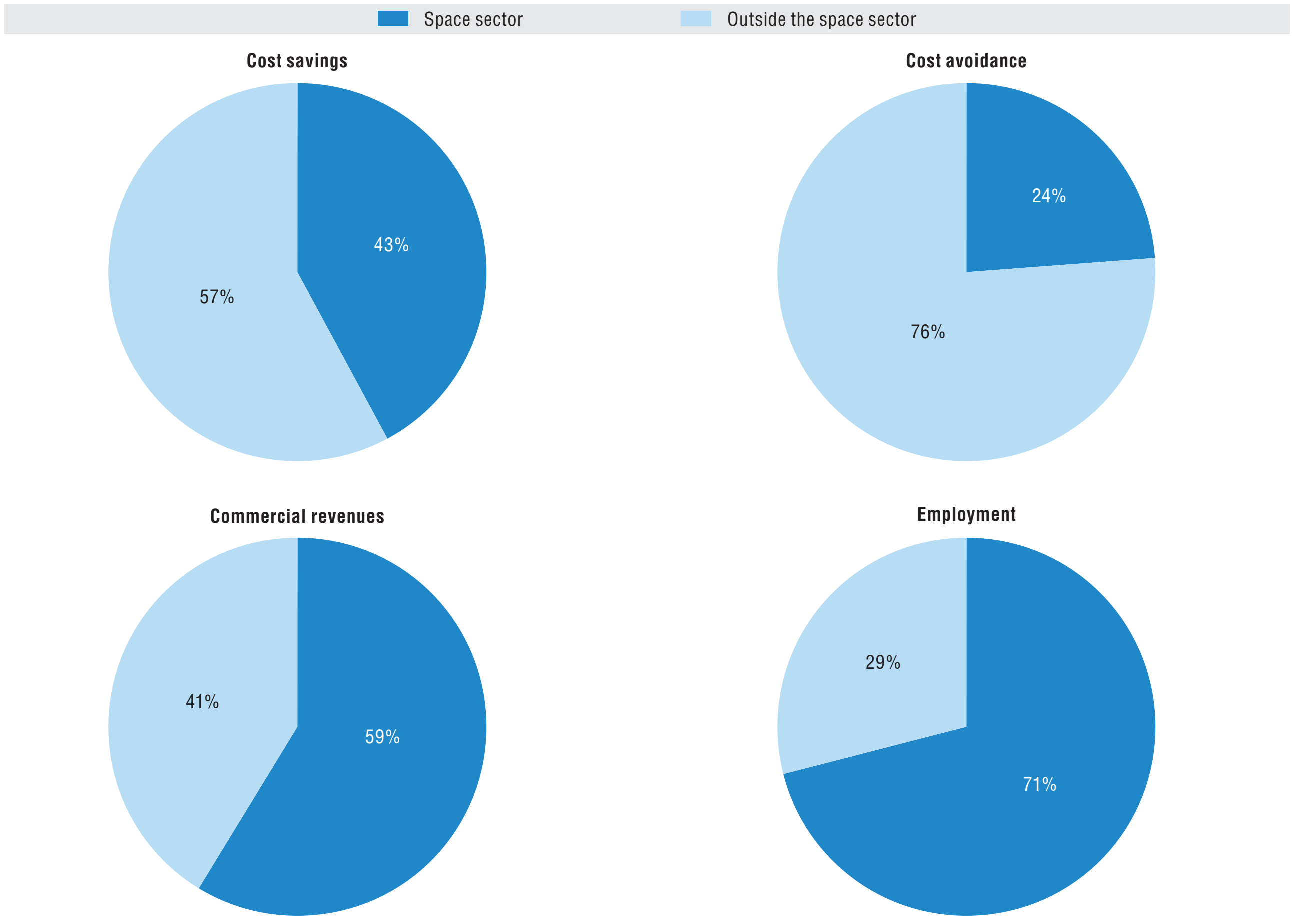
Share of total occurrences identified in the literature



Note: The literature covers 77 impact assessments and programme evaluations published between 1972 and 2018.

Figure 2.3. Benefits in and outside the space sector derived from space investments

As a share of the total listed benefits found in the literature

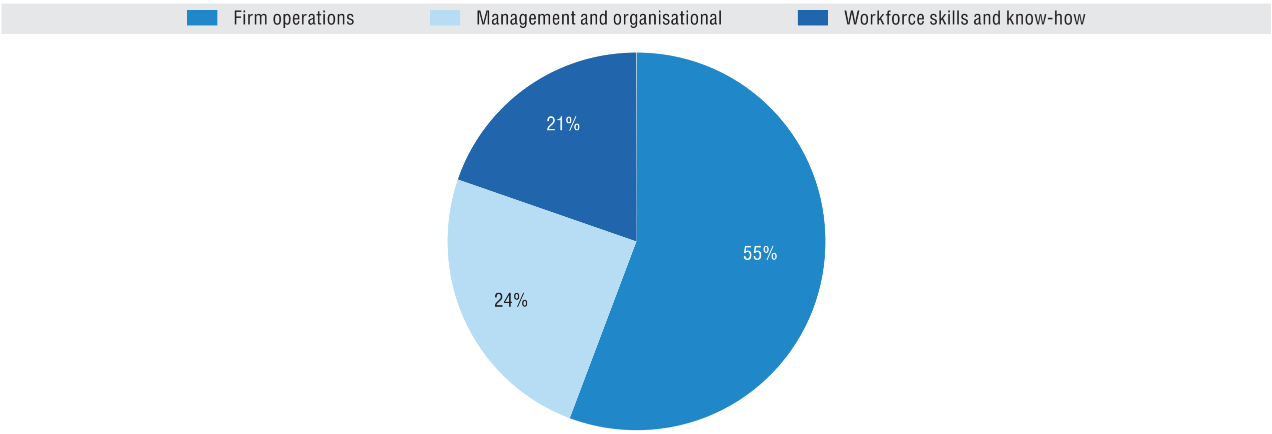


Note: The literature covers 77 impact assessments and programme evaluations published between 1972 and 2018.

The majority of efficiency and productivity gains appear at the level of operations and processes (Figure 2.4). More than half of these benefits (55%) involve better and more efficient production processes and operations that may eventually translate, later on, to cost savings. The rest is almost equally distributed among gains at the workforce (21%) and management (24%) levels. Gains at the workforce level entail boosts of productivity and efficiency resulting from improvements in the workforce's skills and know-how. Gains at the management level comprise all types of improvements coming from better managerial decisions. Improvements include the introduction of more efficient organisational practices, better co-ordination among different business branches and increased external co-operation among firms.

Figure 2.4. Types of efficiency and productivity gains derived from space investments

As a share of the efficiency and productivity gains' benefits found in the literature



Note: The literature covers 77 impact assessments and programme evaluations published between 1972 and 2018.

This international literature review is one useful step in the evaluation and impact assessment of space programmes. Further OECD research will contribute to enhance this growing knowledge base.

Space technologies and the developing world

Despite the daunting challenges facing the developing world, significant, untapped opportunities arise from advances in technology, science and innovation (OECD, 2016[1]). The relevance and take-up of many space applications in developing countries have been growing, thanks to the possibility of accessing many of these information-related technologies more easily and more competitively. This section provides new OECD indicators to track the growing links between development projects and applications of space technologies via official development assistance (ODA) statistics, and then provides some illustrations of existing development projects.

Space technologies and official development assistance

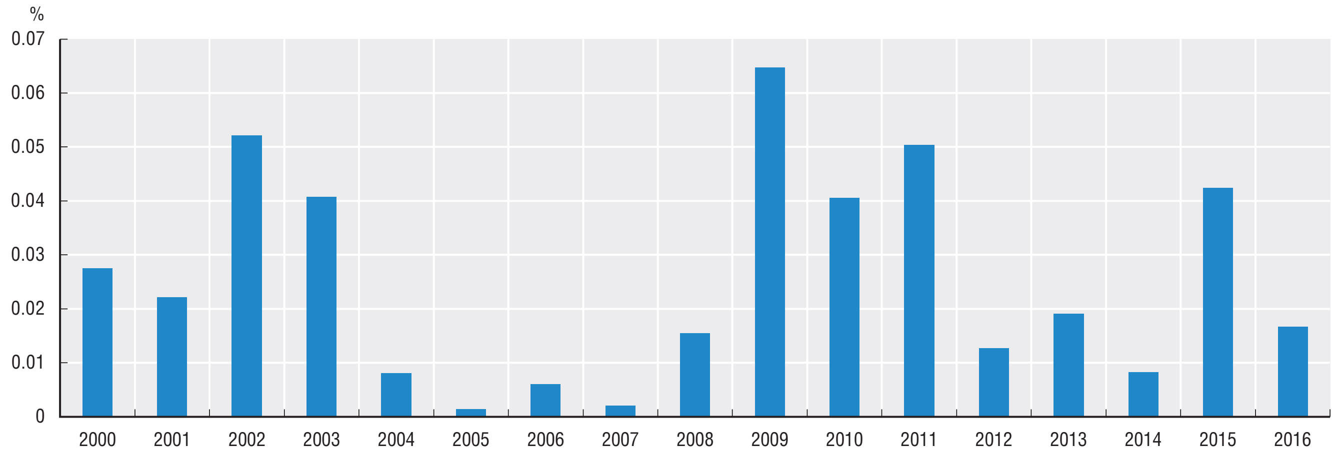
There is growing evidence of the role satellite technologies can play in supporting development objectives. Earth observation (geospatial information, satellite imagery, remote sensing), satellite telecommunication and broadband, as well as global positioning and navigation technologies find many applications specifically targeted for development. They may support the setting up of diverse infrastructure (water, road, transport, telecommunications) or contribute to natural resources management and tackling environmental issues, as in the case of land cover changes and disaster risk prevention and response. Particularly in developing regions characterised by scarce population density and complex urbanisation dynamics, satellite data can improve the implementation of a wide range of development policies at the local, regional and national level. These include public service provision and investment strategies, as well as decentralisation policies (Moriconi-Ebrard, Harre and Heinrigs, 2016[2]). And satellite remote sensing has already been game-changing in several sub-Saharan countries for providing epidemiology information to help contain malaria outbreaks.

In this context, the role of space in official development assistance (ODA) statistics is examined, based on international data curated by the OECD's Development Co-operation Directorate. ODA is today the key measure used in practically all aid targets and assessments of aid performance towards the developing world. The original OECD indicators presented here provide new evidence on the intensifying links between development aid and space applications between 2000 and 2016. Space-related projects were identified using keyword searches in the OECD ODA project database (see Box 2.1), identifying some 2 100 projects over the 2000-16 period. The results are presented in the following paragraphs, identifying some of the most active institutions and countries in terms of funding (via commitments and/or disbursements), main recipient regions, as well as the main fields of application.

Although not negligible, the ODA amounts directed to space-related projects remain modest when compared with overall ODA funding, as illustrated in Figure 2.5. Total overall ODA commitments globally increased from USD 96 billion to USD 188 billion between 2000 and 2016. In comparison, the total committed amounts for space-related official development assistance projects between 2000-16 totalled USD 607.4 million. There are big annual variations, with peaks in 2009 (USD 101 million) and in 2015 (USD 78 million), mainly due to large one-off projects. The 2009 peak is partially explained by a French initiative launched to develop an environment and disaster monitoring small satellite (VNREADSat-1) in Viet Nam.

Figure 2.5. Commitments for space-related official development assistance projects

As a share of total ODA



Source: Calculations based on OECD-DAC database (2018).

Figures 2.6 and 2.7 show ODA project funding statistics for individual donor countries and institutions between 2000 and 2016 (2002-16 for disbursements). Top donor countries generally include countries with big space programmes (United States, France, Japan) and/or countries with dedicated programmes for using space technologies in development aid, including the SERVIR programme of NASA and the US Aid Development Agency, the UK Space Agency International Partnership Programme and Netherlands' Geo-Data for Agriculture and Water programme.

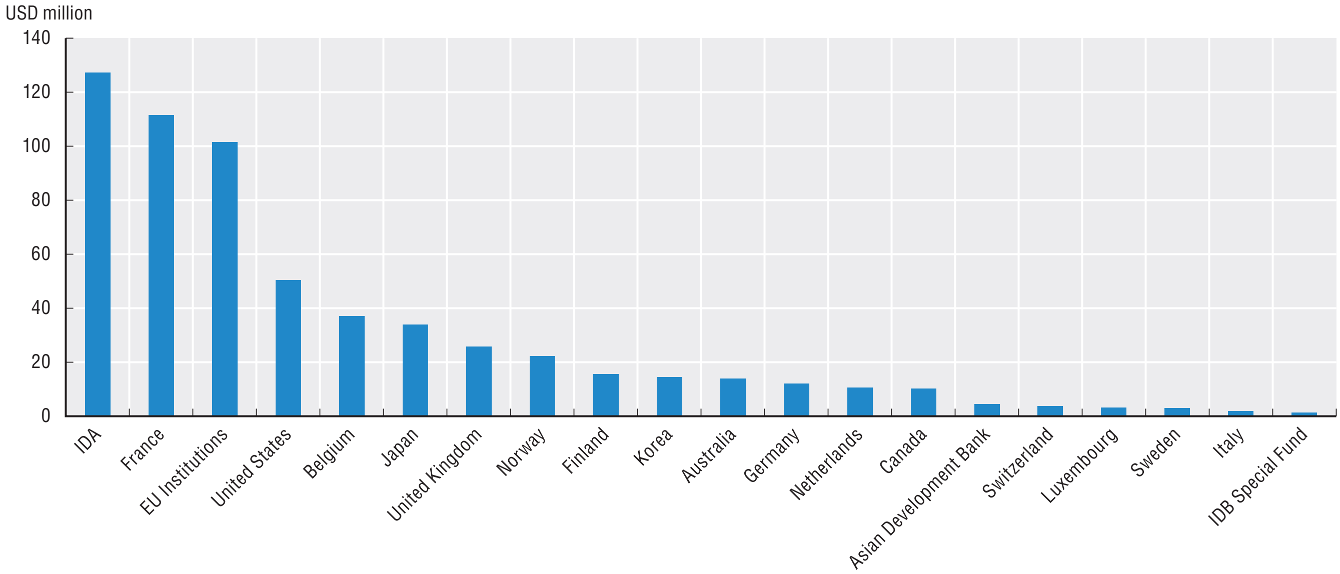
Individual country funding may be channelled either bilaterally or via multilateral organisations (e.g. World Bank/IDA) making funding amounts higher than what is reflected in the figures. Furthermore, the choice of the indicator (ODA commitments or ODA disbursements) may significantly influence the funding amount recorded for a specific year and country. Commitments represent the amount that an actor obliges itself to pay to support a specific project or initiative. In contrast, disbursements represent the amount concretely spent over a determined period (see Box 2.1 for details). Amounts recorded as commitments and disbursements may differ significantly in the short- and medium term, but should normally align in the long run. For instance, it can take several years to fully disburse a commitment. This is due to many concurring factors, including the payment schemes adopted, the nature of the payments and the obligations contracted, as well as their timing, and the selected reporting framework and rules.

If focusing on ODA commitments, the International Development Association (IDA) of the World Bank committed the largest amount of ODA in space projects between 2000 and 2016 (Figure 2.6), followed by

France, the European Union (EU) and the United States. Over the period, the World Bank/IDA committed around USD 127 million, France committed some USD 111.4 million and the United States USD 50.6 million. Among French commitments, one single project accounted for more than half of the total committed amount (USD 65.5 million). This refers to an initiative in Viet Nam, signed in 2009, for the development of an environment and disaster monitoring small satellite (VNREADSat-1), as already mentioned above.

Figure 2.6. Commitments for space-related official development assistance by donor, 2000-16

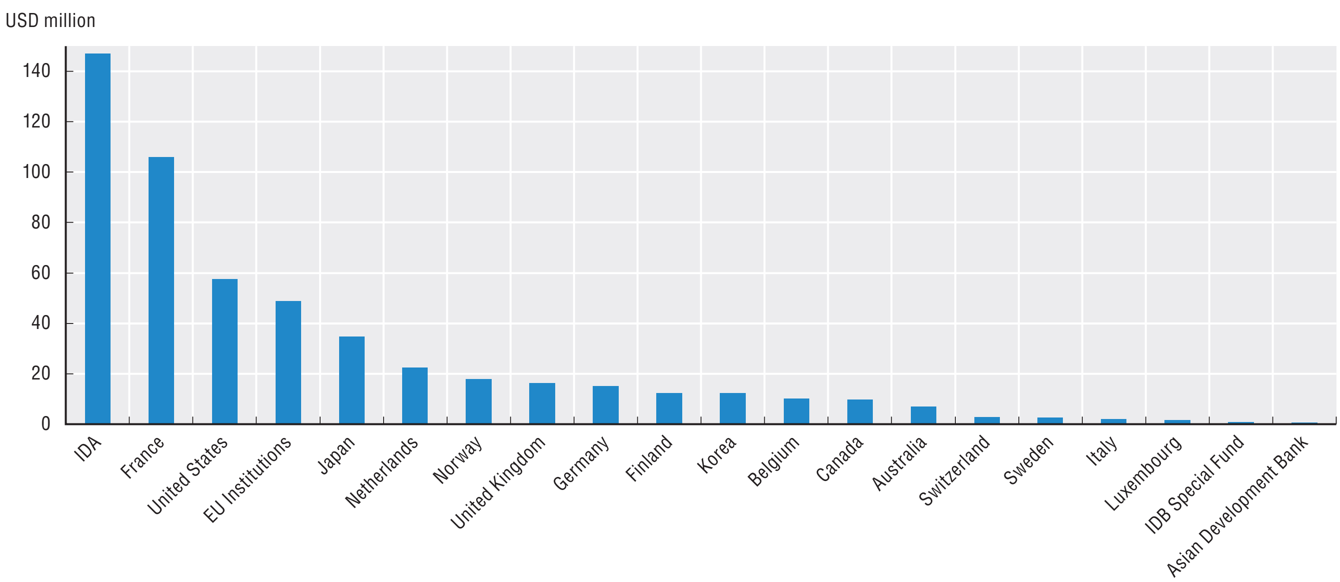
Amounts expressed in constant 2016 USD



Source: Calculations based on OECD-DAC database (2018).

Figure 2.7. Disbursements for space-related official development assistance by donor, 2002-16

Amounts expressed in constant 2016 USD



Note: Due to a change in the reporting guidelines on disbursements in 2002, the figure reports about the period 2002-16 instead of 2000-16 to ensure data robustness.

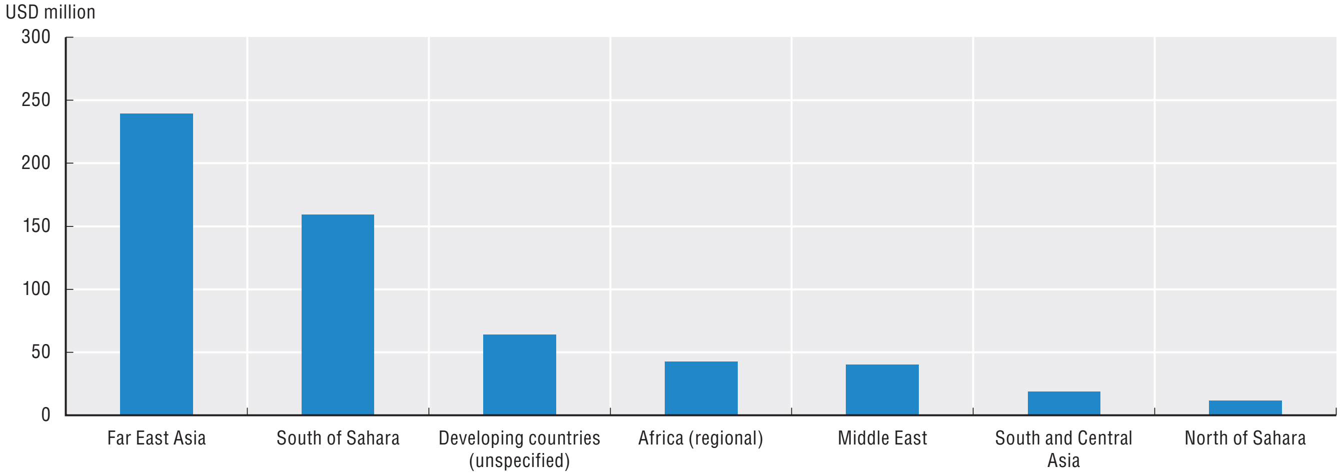
Source: Calculations based on OECD-DAC database (2018).

In terms of space-related ODA disbursements, i.e. money actually spent, IDA, France, the European Union and the United States were the main contributors, followed by Japan (USD 35 million) and the Netherlands (23 million).

Figure 2.8 shows the main regions receiving space-related ODA in the 2000-16 period. The majority of space-related ODA commitments was directed to countries in Far East Asia (East and Southeast Asia), receiving USD 240 million, and Sub-Saharan Africa (USD 160 million). Several projects targeted more than one country, at which case funding was allocated at regional level. The African region has been the target of several such initiatives, receiving USD 43 million in commitments. Several ODA projects do not specify the recipient name or region ('developing countries (unspecified)').

Figure 2.8. Commitments for space-related official development assistance projects by recipient region, 2000-16

Amounts expressed in constant 2016 USD



Note: The category "Africa (regional)" indicates that money was allocated at regional level, targeting more than one country at the same time. The category "Developing countries (unspecified)" is used when no specific recipient was indicated by the ODA project description.

Source: Calculations based on OECD-DAC database (2018).

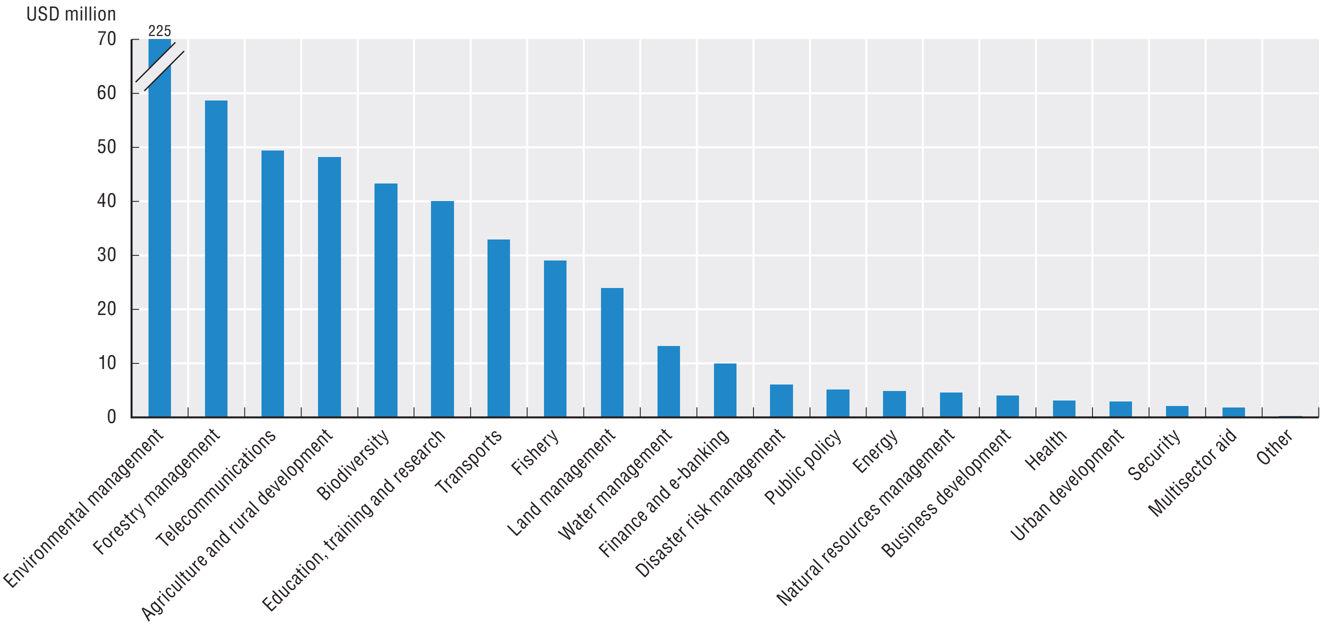
In terms of fields of application, most of the funding has been allocated to projects linked to environmental management objectives (Figure 2.9). Projects in this domain represent USD 225 million between 2000 and 2016. This is followed by forestry management (USD 59 million), telecommunications (USD 49 million) and agriculture and rural development (USD 48 million). A review of the projects included in the datasets finds that:

- Environmental management projects typically adopt satellite technologies to improve the analysis and the use of the environment and related resources, often linked to climate change. Projects tend to be quite large, with a broad regional scope. Satellite remote sensing is used to support and improve decision-making. The bulk of the initiatives are not only aimed at promoting a better use of environmental resources, but also at making environmental monitoring more effective.
- Forestry management projects focus on challenges linked to the sustainable use and conservation of forests. Remote sensing technologies are used to assess the conditions of forests, mapping, gathering data and building databases for monitoring purposes.
- Telecommunications projects deal with the development, or expansion, of regional/national telecommunication infrastructure, involving the provision of satellite broadband and broadcast services. Projects are generally large, aiming to connect remotely located households and communities to the existing telecommunication networks.

Other relevant thematic clusters include agriculture and rural development, biodiversity and education, training and research. Projects listed under 'agriculture and rural development' include all projects exploiting satellite images and data to inform agricultural practices, monitor agricultural resources and assess agricultural productivity. Several initiatives specifically aim at promoting food security as a direct consequence of greater crop production and better functioning of early warning systems and climate condition monitoring. Projects linked to biodiversity protection use remote sensing techniques for biosphere and animal protection. Several applications also include the adoption of GNSS technologies to track species and their dislocation across different geographic areas. Finally, education, training and research projects group the bulk of distance-learning initiatives focusing on the provision of tele-education services to populations living in remote areas.

Figure 2.9. Space-related official development assistance commitments by project purpose, 2000-16

Amounts expressed in constant 2016 USD



Source: Calculations based on OECD-DAC database (2018).

Box 2.1. Official development assistance at the OECD

The OECD's Development Co-operation Directorate has been in charge of measuring resource flows to developing countries since 1961, with particular attention given to the official and concessional part of this flow, defined as "official development assistance", or ODA. In close collaboration with Development Co-operation Directorate colleagues, the OECD Space Forum Secretariat has explored the Development Assistance Committee's databases using keyword searches. The original dataset has been manually checked and cleaned, to identify and retain only the projects dealing with space-related initiatives. Some 2 100 ODA projects featuring satellite applications or technologies were identified over a 16-year period (2000-16).

ODA takes place through transfers of resources, either in cash or in the form of commodities or services. They can be provided in many different ways, usually including privileged loans, grants or even technical assistance.

ODA can be bilateral or multilateral, provided from a donor to a specific recipient or channelled through the action of a development agency. Bilateral aid represents the "flow from official (government) sources directly to official sources in the recipient country". Multilateral aid represents "core contributions from official (government) sources to multilateral agencies where it is then used to fund the multilateral agencies' own programmes". A donor can also decide to charge a multilateral agency with delivering a programme or project on its behalf in a recipient country.

Box 2.1. Official development assistance at the OECD *(cont.)*

ODA is reported in different ways, either as ODA commitments or ODA disbursements.

- An ODA *commitment* is a firm obligation, expressed in writing and backed by the necessary funds, undertaken by an official donor to provide specified assistance to a recipient country or a multilateral organisation. Bilateral commitments are recorded in the full amount of expected transfer, irrespective of the time required for the completion of disbursements. Commitments to multilateral organisations are reported as the sum of (i) any disbursements in the year reported on which have not previously been notified as commitments and (ii) expected disbursements in the following year.
- An *ODA disbursement* is the release of funds to or the purchase of goods or services for a recipient; by extension, the amount thus spent. Disbursements record the actual international transfer of financial resources, or of goods or services valued at the cost to the donor. In the case of activities carried out in donor countries, such as training, administration or public awareness programmes, disbursement is taken to have occurred when the funds have been transferred to the service provider or the recipient. They may be recorded gross (the total amount disbursed over a given accounting period) or net (the gross amount less any repayments of loan principal or recoveries on grants received during the same period). It can take several years to disburse a commitment.

Source: OECD (2018[3]), *DAC Glossary of Key Terms and Concepts*, *http://www.oecd.org/dac/*.

Illustrations of technical assistance projects

A majority of countries with a space programme and private actors operative in the space sector have launched specific technical assistance projects promoting socio-economic development (Table 2.1). They include applications aimed at improving the coverage of the medical system in remote areas, preventing the diffusion of diseases, providing classes and training through tele-education channels and supporting policies for the management of resources and the prevention of natural disasters.

Table 2.1. Selected illustrations of space for development initiatives from around the world

Programme	Organisations involved	Short description	Technologies and domains of application	Geographic focus	Potential benefits
Tele-epidemiology initiatives	CNES (France)	Several projects using earth observation in the area of tele-epidemiology to prevent the diffusion of contagious diseases. Combining environmental variables with satellite imagery, it is possible to draw predictive risk maps able to track the exposure to disease-bearing insects and ideally create widely applicable early warning systems.	Earth observation for tele-epidemiology, health monitoring, disease prevention, agriculture (livestock)	Argentina, Burkina Faso, Chad, China, Mali, Martinique, Mediterranean basin, Senegal	Lives saved, lives improved, cost avoidance (agriculture)
Land subsidence in Jakarta	European Space Agency with World Bank, Jakarta municipal government	Flood risk management project in the Jakarta metropolitan area run by the World Bank. This includes revitalisation of drainage canals and a collection of detailed geospatial information (through COSMO Sky-Med data) concerning flood hazard and an assessment of the existing capacity of the hydraulic networks and investigations of land subsidence patterns.	Earth observation, geospatial information, persistent scatterer interferometry for environmental management, disaster risk management and prevention, urban planning	Indonesia	Cost avoidance, cost savings, efficiency, lives improved
GMES and Africa initiative	European Commission (DG DEVCO) with African Union, GMES Africa Unit	The project facilitates the establishment of systems to receive and process earth observation and geo-data and disseminate relevant information in Africa. It also enables the development of capacities of experts in acquiring wider and deeper knowledge on earth observation techniques and environmental issues.	Earth observation, geospatial information for water management, natural resources management, marine and coastal management	Africa (whole continent)	n.a.

Table 2.1. Selected illustrations of space for development initiatives from around the world *(cont.)*

Programme	Organisations involved	Short description	Technologies and domains of application	Geographic focus	Potential benefits
Telemedicine programme	Indian Space Research Organisation with local governments	The programme started in 2001 with the goal of using satellite communications in the provision of health services to people living in remote areas. The goal of the project is to connect remote college hospitals and mobile telemedicine units to major specialty hospitals in cities and towns through Indian satellites. Thanks to satellite links it is possible to provide medical diagnosis and consultation by specialist doctors to patients located in remote and rural areas.	Satellite broadband for telemedicine	India	Lives saved, lives improved
SERVIR	National Aeronautics and Space Administration (NASA) with US Agency for International Development (USAID)	Partnership between NASA and USAID exploiting earth observation for environmental management purposes in more than 30 developing countries. The goal is to help local governments improve their response to natural disasters, tackle food security, safeguard human health, and manage water and natural resources.	Earth observation, satellite imagery, geospatial information, science applications for environmental management, land use and land cover, disaster risk management and prevention, water management, agriculture, food security	Hindu-Kush region (Himalayas), Lower Mekong River basin, eastern Africa, southern Africa	Environmental effects, lives saved, lives improved, cost avoidance (agriculture)
Geodata for Agriculture and Water (G4AW)	Netherlands Space Office (NSO) with local partners in each country	Using EO data and satellite broadband to provide developing economies with information on climate, weather and hazards and help food producers and other stakeholders. The goals are to: improve the output of the agricultural, pastoral and fishing sector; reach a minimum 10% increase in sustainable food production; help achieve a 10% more effective use of inputs; and promote sustainable improvement and increase of food production.	Geospatial information, satellite broadband for agriculture	Bangladesh, Burkina Faso, Ethiopia, Indonesia, Kenya, Mali, South Africa, Tanzania, Uganda, Viet Nam	Increased agricultural productivity, increased agricultural turnover
International Partnership Programme (IPP)	UK Space Agency with different partners according to country and programme	The IPP is a five-year GBP 152 million programme which seeks to maximise the practical impact on the lives of those living in developing countries by partnering with these countries to use space solutions to solve their specific development challenges. The programme is delivered through a series of calls run by the UK Space Agency's IPP team. Several projects are registered under the IPP umbrella in many regions and countries in the world.	Earth observation, geospatial information for health, education, deforestation, disaster response, land-use monitoring, maritime sector, renewable energy	Sub-Saharan Africa, Latin America and the Caribbean, South East Asia	Environmental effects, lives saved, lives improved

Illustrations for three domains of space applications are provided below: health, education, and natural resources and land-use management.

Health

The national health system represents a crucial sector for developing economies, and the use of specific satellite technologies have been demonstrated over the years to tackle specific challenges. This includes reaching populations living in remote areas to provide them with basic medical services, consultations and the sharing of patients' data with specialists. Epidemiology is another promising field using satellite imagery to track the diffusion of diseases and disease-bearing insects (e.g. malaria).

The Indian Space Research Organisation (ISRO) is very active in applying satellite technologies, and broadband in particular, to provide health services to its very widespread population. ISRO's Telemedicine Programme started in 2001 with the goal of using satellites to provide health services to people living in isolated areas. The goal of the project is to connect remote college hospitals and so-called mobile telemedicine units to major specialty hospitals in cities and towns through Indian satellites. Thanks to satellite links, it is possible to provide medical diagnosis and consultation by specialist doctors to patients which otherwise could not be reached. The network includes 384 hospitals, with 60 specialty hospitals connected to 306 remote college hospitals and 18 mobile telemedicine units. The latter are operative in the areas of ophthalmology, cardiology, radiology, diabetology, mammography, general medicine, and women's and children's health (ISRO, 2017[4]).

Private actors are also increasingly playing a significant role in the health sector, making available their assets and expertise for the provision of services. Inmarsat launched an e-health project in collaboration with the charity SOS Children's Villages in Benin (Inmarsat, 2014[5]). The initiative makes it possible for rural community health clinics to send patients' medical information to doctors in urban hospitals via Inmarsat`s broadband data service infrastructure. About 1 350 children and their families have been helped thanks to improved health monitoring and early diagnosis of conditions.

As another illustration, the French space agency (Centre national d'études spatiales, CNES) is currently running several projects using earth observation in the area of tele-epidemiology to prevent the diffusion of contagious diseases. CNES has developed a deterministic approach based on the relationship between climate, environment and health relationships, to monitor, predict and prevent epidemics (Vignolles, 2011[6]). Combining environmental variables with satellite imagery, it is possible to draw predictive risk maps able to track the exposure to disease-bearing insects. This concept is currently applied to track the diffusion of malaria (Argentina, Burkina Faso, Chad, Mali and Senegal), bilharzia (The People's Republic of China), vibrio (Mediterranean basin) and dengue (Argentina and Martinique). The idea is to develop early warning systems applicable to a wider array of diseases in other places with different environmental characteristics.

Education

Similarly to telemedicine, education also benefits from satellite connectivity as a means to reach populations living in remote areas thanks to tele-education. In some countries, mobile learning centres as well as schools are increasingly equipped with ground stations transmitting via satellite different types of learning services, including classes, courses, interactive exercises and trainings. In 2004, ISRO launched a tele-education initiative, the EDUSAT programme, aimed at bringing education to every corner of the country. EDUSAT is the first satellite entirely used in the country for the provision of education services. They are delivered through a wide range of interactive educational channels like one-way TV broadcast, video conferencing, computer conferencing and web-based instructions (ISRO, 2017[7]). The established network includes two types of terminals, namely satellite interactive terminals and receive-only terminals. As of December 2012, 83 networks had been implemented connecting to 56 164 schools and colleges (4 943 satellite interactive terminals and 51 221 receive-only terminals) covering 26 states and 3 union territories of the country. Estimates indicate that about 15 million students benefit from the EDUSAT programme every year.

Satellites are also very useful for civilians in the case of conflicts that make entire regions impossible to access for long periods of time. For example, Inmarsat, partnering with Télécoms Sans Frontières, used satellite broadband to provide classes to children caught up in the conflict in Iraq (Inmarsat, 2014[8]). Services were provided through mobile e-learning centres located in refugee camps. The centres allow children to access the Internet via Inmarsat's broadband global area network (BGAN) service using digital tablets.

Natural resources and land-use management

Natural resources and land-use management are two areas which are particularly suitable for the application of satellite earth observation. Different types of satellite imagery integrated with other data sources are now commonly used to better inform decision-making processes and disaster management processes, monitor land cover and land-use change, as well as water, and to control the use of resources to promote food security and sustainable development. Even in the case of setting up cadastral information and urban agglomerations maps, satellite data play an increasing role, as demonstrated by ongoing activities of the OECD Sahel and West Africa Club (Box 2.2).

In order to help local governments improve their response to natural disasters, tackle food security, safeguard human health, manage water and natural resources, the SERVIR initiative was set up in 2004 as a then very original partnership between the National Aeronautics Space Administration (NASA) and the US Agency for International Development (USAID). The programme uses satellite-based earth monitoring, imaging and mapping data, geospatial information, predictive models, and science applications to help improve environmental decision-making in co-ordination with agencies in developing economies (NASA, 2017[10]). The initiative now runs in more than 30 developing countries. Within the programme, NASA partners with leading regional organisations in eastern and southern Africa, the Hindu-Kush region of the Himalayas, and the lower Mekong River Basin in Southeast Asia. In the Himalaya region, earth observation data are used to detect forest fires, monitor land-use and cover changes as well as water resources. In Africa, the main target of the initiative is flood forecasting, monitoring the impact of frost on regional agriculture and again assessing land cover and land-use change. Activities in the Mekong region focus instead on disaster risk reduction and response, together with water and food security, landscape management to reduce greenhouse gas emissions, and sustainability of the river basin.

Box 2.2. Africapolis, an initiative from the OECD Sahel and West Africa Club

Combining census data with satellite imagery to build a homogenous, independent and verifiable database on urban agglomerations in Africa.

Africa is set to have the fastest urban growth rate in the world in the coming decades, with the number of people living in cities and towns projected to double over the next 20 years. Cities are and will increasingly be a defining feature of Africa's social, economic and political landscape. There is a need to understand urbanisation – what it looks like, what it means and what it might mean in the future. More complete and up-to-date data are crucial in order to document and analyse the ongoing dynamics of urbanisation and to provide the evidence base for a wide variety of public policies.

The Africapolis database produced by the OECD Sahel and West Africa Club is a unique database on cities and urbanisation dynamics in Africa. The 2018 edition covers 51 countries and provides information on the number of inhabitants, the size of built-up areas and geolocation for 7 500 urban agglomerations with more than 10 000 inhabitants between 1950 and 2015. The uniqueness of the Africapolis database comes from a combination of features that make it comparable across countries and time, rendering it independent of national definitions and verifiable.

The methodology combines census data and other official population counts, with satellite and aerial imagery and other cartographic resources. In many African countries, censuses are carried out infrequently, during different years, are based on country-specific definitions and provide different levels of detail. The integration of satellite imagery is therefore necessary for building a homogenous database. The application of a morphological definition to an urban agglomeration is verifiable – it is observable on the ground, and it allows for the detection of a number of key features such as urban sprawl, connectivity, the formation of metropolitan areas and the emergence of new agglomerations. Given the pace of urbanisation dynamics in Africa, these features are particularly important for policy analyses and design, ranging from provision and accessibility of basic public services to accessibility to jobs, public transport provision and funding needs, resource efficiency and sustainability, and the design of appropriate governance structures and agencies.

Source: OECD Sahel and West Africa Club (SWAC) (2018[9]).

Other space agencies and organisations are using earth observation for development purposes, often partnering with aid agencies and institutions in various parts of the world (Table 2.1). The Japan Aerospace Exploration Agency (JAXA) is collaborating with the Asian Development Bank on projects in the region where space applications serve mainly agriculture and rural development (ADB, 2013[11]). The UK Space Agency's International Partnership Programme (IPP) is a GBP 150 million multiyear programme launched in 2015. The explicit goal is to use space expertise and knowledge to deliver socio-economic benefits to underdeveloped economies (UK Space Agency, 2017[12]). Within it, several cross-sectoral projects have already been implemented in partnership with local governments, aid organisations and private actors in the area of land-use and natural resources management. Other initiatives include the one by the European Commission and JRC boosting the use of Copernicus data in Africa (European Commission Joint Research Centre (JRC), 2017[13]), and the Netherlands Space Office's Geo-Data for Agriculture and Water programme (G4AW) (Netherlands Space Office, 2016[14]).

Impacts of space technology transfers

The process through which a technology originated in one sector finds an application in another sector is called technology transfer. The term indicates every "movement of know-how, skills, technical knowledge, procedures, methods, expertise or technology from one organisational setting to another" (Roessner, J, 2000[15]). Studying this mechanism sheds light on the path followed by ideas and knowledge from the moment they are created to the moment when they are transferred and find a concrete application in the marketplace.

Technology transfers and their commercialisation contribute to foster broader socio-economic development, thanks in particular to their impact on innovation in different sectors (OECD, 2017[17]). Technology transfers act as a strategic channel to stimulate and trigger innovation creation and propagation mechanisms, by means of knowledge spillovers through industryscience collaborations and technology transactions among various actors (OECD, 2016[18]); (OECD, 2017[17]). They do so primarily by inducing direct economic benefits to industry, for example, by boosting productivity and increasing the number of jobs created, but also by improving people's well-being and addressing critical societal challenges.

The interest for technology transfers from the space sector to other sectors of the economy has been growing over recent years, reflecting the increasing focus on space applications and their potential for generating socio-economic benefits beyond space missions, for the economy and society (Jolly and Olivari, forthcoming[16]). Space technology transfers have moved from being often accidental by-products of space research, to new ways to multiply the value of original space R&D. Promoting the diffusion of space technologies is becoming a significant task in space agencies' programme of work in many countries.

Technology transfers and commercialisation (TTCs) aim to extend the benefits of space R&D investments and maximising their returns. When the transfer is timely and well organised, technology recipients may reduce the costs necessary to introduce new advanced technologies, in terms of time and funding (ESA, 2017[19]). They may benefit from enhanced productivity and efficiency in production processes and may be able to offer a larger portfolio of more competitive products. These newly developed goods and services can lead to new markets. For the general public, such transfers are also very useful, as the space R&D can appear as contributing other socio-economic benefits beyond initial space missions, building a case for increasing public and private space investments.

This virtuous process is not automatic and depends on several concurrent factors and strategic decisions. The likelihood of TTCs taking place depends on the characteristics of the technology to be transferred, of the objectives of the R&D programme where the technology has originated and of the R&D network of actors receiving it. In addition, policy makers have a fundamental role to play in creating the right environment and institutional framework which facilitate the diffusion of technologies. The recipients of new technologies are also important, in particular in the commercialisation phase. Their vision is crucial in disclosing the potential of the assets they receive. This includes testing them in specific applications, adapting and upgrading them to respond to the needs of the market they serve or aim to serve, and getting a monetary value out of the process.

Assessing the effects of space TTCs

Assessing the effects of commercialised technologies is a difficult task, particularly in the space sector. In order to make the effects generated identifiable and therefore allowing for a more immediate evaluation, some indicators of impact of space TTCs can be identified, and generally include: jobs created, revenues generated, productivity and efficiency gains, lives saved/not lost and lives improved (Table 2.2).

Table 2.2. Selected benefits derived from space technology transfers

Category of benefits	Measurement
Jobs created	Number of people hired to produce or use a space-derived product or service.
Revenues generated	Estimation of revenues generated by a company producing or offering a product or service that is a spin-off of space technology.
Productivity/efficiency gains	Quantification of saved and/or avoided costs due to the use of space-derived products or services, either by the company or by its customers.
Lives saved/not lost	Number of lives not lost as a result of a product or service that is a direct application or spin-off of space technology.
Lives improved	Number of people whose lives have been extended, enhanced and/or improved by a product or service that is a direct application or spin-off of space technology.

All of these can generically be defined as indirect effects from space programmes and be further classified in:

- *Technological effects*: effects produced by the direct application of the new space-related technology by the recipient actors.
- *Commercial effects*: can appear as network effects – i.e. impact of the space programme on the network in which the recipient actor operates – and reputation effects – i.e. boost in an actor's relative prestige and reputation within its network.
- *Organisational effects*: increased experience and know-how, as well as learning, derived from the collaboration between space and non-space actors in developing and exploiting new technologies.
- *Work factor effects*: impacts on employees acquiring new skills, capabilities and expertise with the potential of feeding that into other departments of the organisation for which they work.

Traditional assessment frameworks, involving macroeconomic modelling, econometrics, input-output multipliers and cost-benefit analysis, are not always suitable to measure such impacts. For instance, assessing the effects of transfers must often rely on ad hoc analysis to control for case specificity and subjectivity at a micro level. The relevant TTCs' effects are often evident from the firm and user perspective, rather than in the economy at large. Particular attention must be given to: the identification of causality linkages, the use of ad hoc methodologies and the definition of the right units of measure through which to quantify the effects of TTCs.

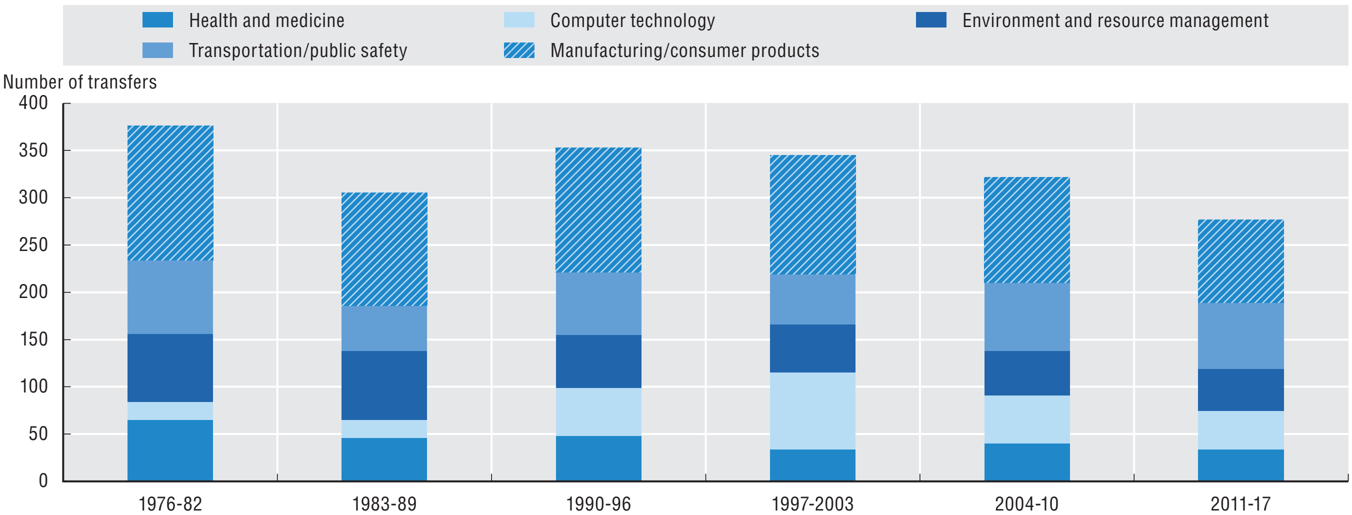
Examples of successful transfers from the space sector

Several examples of technology transfers exist and are recorded, as space organisations are increasingly tracking positive transfer stories. Successful use cases can be found in areas like health, transportation, consumer goods, air quality control and public safety, just to name a few (summarised in Table 2.3). In some cases, technologies are developed within space programmes with the predetermined goal of addressing clear needs in a specific sector. In others, opportunities of application and commercialisation appear later, with unexpected uses arising in different fields. The Space Shuttle programme, for example, is a leading illustration of this second group (see Box 2.3). The programme was able to influence several sectors in different moments during the decades following its first launch. Many of the technologies developed for the Shuttle, and to serve its operationalisation, spurred over the years and impacted a number of areas ranging from health to transportation and consumer goods.

The National Aeronautics and Space Administration (NASA) in the United States has documented nearly 2 000 commercial products and services successfully developed between 1976 and 2018. The majority of them have been recorded in the sectors of manufacturing and consumer products, with an average of 18 products per year over the 41 years analysed by NASA (Figure 2.10). Other relevant socio-economic sectors of application are transportation and public safety (nine per year), environment and resource management (eight), health and medicine (seven), and computer technology (six). As an illustration, a cardiac imaging system developed commercially by the medical industry in 1990, derived from camera technologies on board NASA Earth resources survey satellites. The benefit was, at the time, significantly improved real-time medical imaging, with the ability to employ image enhancement techniques to bring out added details while using a cordless control unit (NASA, 2018[20]).

Some twenty year ago, the European Space Agency mapped the sectors developing the highest number of commercial products based on space technologies. This included software solutions, engineering, energy, medical applications, transports and safety and security (ESA, 1999[21]). An analysis of transfers recorded in the ESA Business Incubation Centres' programme from 1990 to 2006 showed that transfers from both the space sciences and launchers programmes produced the highest number of new commercial products, followed by human spaceflight and telecommunications (Szalai, Detsis and Peeters, 2012[22]). More recent documented ESA applications of space technology transfers to different sectors include, for instance, air purification systems in hospital intensive care wards, radar surveying of tunnel rock to improve the safety of miners, and enhanced materials for a wide variety of products from racing yachts to running shoes (ESA, 2016[23]).

Figure 2.10. NASA technology transfers to different economic sectors



Source: OECD calculations based on NASA spin-offs database (2018).

Overall, there are many recorded examples of space technology transfers to medical applications in different space agencies. Based on ultrasound probes developed during the first French human spaceflights in the early 1980s, innovative echocardiography probes were developed and commercialised by a still very active spin-off firm, with cumulated sales representing around EUR 200 million (CNES, 2014[24]). Recently, the German Aerospace Center's Institute for Robotics and Mechatronics licensed space technologies used on the International Space Station to a large medical equipment company to develop commercial robotic arms for surgery (DLR, 2016[25]).The Italian Space Agency (ASI) has supported several technology transfer projects over the years as well. The Microfluidics and the Mach-Zehnder projects are just two examples where ASI promoted an "earth-space-earth" technology cycle: assets developed in a non-space sector have been initially applied and upgraded in space, to be finally adapted and patented for commercial uses in down-to-earth applications (Verbano and Venturini, 2012[26]).

Table 2.3. Selected examples and applications of space technology transfers

Space programme	Technologies transferred	Applications outside space	Areas of application
NASA investments in life sciences research	Investments in life sciences research and development of related technologies	Development of more efficient medical and research equipment and research activities	Health and medicine
Italian Microfluidics project	Micro-propulsion system to control and regulate a satellite's tilt	Technologies for healthcare and membrane filtration and research activities	Health and medicine
Italian Mach-Zehnder project	Microinterferometer, technology to analyse planetary gases	First: technology for the monitoring of air quality and the presence of atmospheric pollutants Second: technology for monitoring fermentation and various chemical processes in wine production	Environmental monitoring and agriculture and food sectors
Research from the Max Planck Institute for Extra-terrestrial Physics (MPE) on ROSAT X-rays	Mathematical algorithm (SIM) used to analyse data from X-ray satellite ROSAT	Development of a computer-aided early recognition system (MELDOQ) to recognise melanomas through digital image analysis	Health and medicine
ESA work on robot calibration	Creation of a new system, the so-called Rodym, exploiting multiple cameras to measure the movement of infrared LED markers on space robots	Rodym is now part of many car manufacturers` production lines to enhance precision, with significant returns in terms of higher production rates and better quality control	Transports and manufacturing
DLR Institute for Robotics and Mechatronics work on remotely controlled robots for the International Space Station (ISS)	Development of robots remotely controlled from Earth or from the ISS giving the operator the impression of being there (e.g. telepresence)	MIRO is a robot remotely controlled by doctors to perform a surgeon's movements with high precision through numerous sensors via partial or total automation	Health and medicine
ESA's Rosetta mission	Technology used in the Ptolemy Instrument for analysing comets	Development by a UK company of a detector that enables the hospitality industry to reproducibly and accurately monitoring for the presence of bed bug infestations	Hospitality industry

Table 2.3. Selected examples and applications of space technology transfers *(cont.)*

Space programme	Technologies transferred	Applications outside space	Areas of application
CNES human spaceflight	Ultrasound probes tested by universities during the first French human spaceflights	Development of innovative echocardiography probes	Health and medicine
Canadian Space Agency's technology tested on the International Space Station (ISS)	Portable Canadian technology that analysed cells and hormones in blood or other biological samples.	Microflow could be used to perform rapid, real-time testing and analysis anywhere in the country, including areas with limited medical equipment, such as remote communities or those affected by natural disasters	Health and medicine
Carré Technologies of Montreal, Quebec, developed Bio-Monitor for the Canadian Space Agency (CSA)	A new wearable technology has been designed to fit into an astronaut's daily routine aboard the International Space Station (ISS) while monitoring and recording vital signs.	An early version ca improve the performance of sport athletes. The next ones have the potential to help Canadians who are bedridden, housebound, or living in rural communities with limited access to medical support. It can also be worn by workers in dangerous environments such as mines, industrial sites, or factories.	Heath and medicine/Sports

Box 2.3. Examples of technology transfers from the Space Shuttle space programme

Initially conceived for uses only within the space sector, the Space Shuttle has produced many benefits thanks to technologies spurred in the process. At least seven areas have been affected, namely health and medicine, transport, public safety, consumer goods, environmental management, computer technology, and industrial productivity (Lockney, 2010[27]). Some examples include:

- *Transport*: In the 1970s, studies on the Space Shuttle's aerodynamic structure inspired a new design for trucks able to reduce aerodynamic drag and boost efficiency through improved fuel autonomy. In 1994, NASA commissioned the development of a new lubricant for the Space Shuttle, safer for the environment, to Sun Coast Chemicals of Daytona Inc. The company also started an entire line of racing products incorporating environmental benefits. In addition, a Florida-based company collaborated with NASA on the development of a new type of foam to be used in the manufacturing of acoustic and thermal insulation. The result was a new flame retardant, which was licensed and also applied as an insulator for NASA cryogenic propellant tanks.
- *Public safety*: Video surveillance technologies used to improve the quality of the Space Shuttle's launch have been exploited in image stabilisation systems widely used in the law enforcement industry and for military missions. That is the case, for example, of video surveillance, crime scene footage, sting operations and several more specific military applications (Lockney, 2010). In addition, infrared cameras used on the Space Shuttle are now adopted to scan for fires, as well as for night vision, early warning systems, navigation and weather monitoring, among others.
- *Consumer goods and services*: A number of parts and tools used in the Space Shuttle have been integrated by companies to develop new goods and services. Examples range from new insulation materials for homes and clothing; cabin flight simulators for exhibits, museums or other events; simulation devices for exhibits; lubricants for hunting and fishing equipment and many others.

The role of policies

Policy and legal frameworks play a key role in initiating, supporting and boosting transfers from the space sector to other fields. Policy-makers are encouraged to mitigate information asymmetries and ensure legal certainty, by defining clear property rights and legal frameworks; strengthen R&D networks using research grants, matching grants and tax incentives, as well as other available policy instruments; promote the role of technology transfer intermediaries, including innovation centres, incubators and technology parks, by using gap funds and mentoring and networking programmes and supporting start-ups; and make transfers a built-in goal of space programmes by acting on public procurement policies.

Given their strong R&D focus with pre-existing portfolios of technologies, software and patents, facilities and expertise, space agencies are uniquely placed to support technology transfers and commercialisation. Several agencies already have online catalogues of patents available for public or commercial use and propose a range of connected services. One example is the NASA Patent Licensing Programme. NASA's patent portfolio which contains more than 1 200 patents that are available for different types of exclusive and non-exclusive licenses. Start-ups can license a selection of these patents with no initial fees (NASA, 2015[28]). Potential applicants may further have the opportunity to observe a technology demonstration or talk to the inventor at different NASA centres.

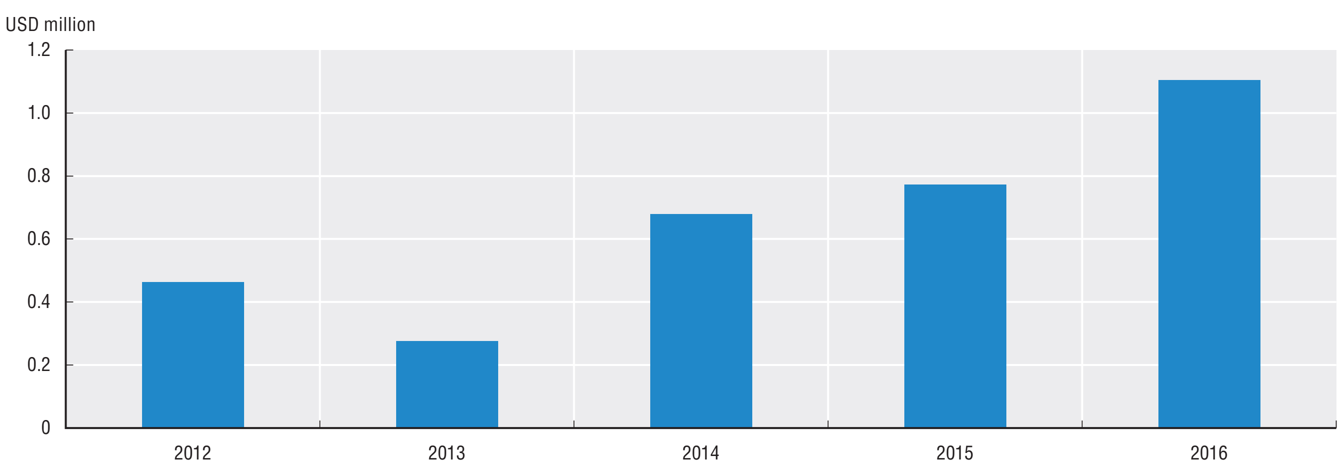
Mentoring programmes providing commercial and technical guidance tend to be a separate, but closely connected activity, which encourages the development of space-related start-ups and strengthens the relationship with private and academic actors. For instance, the technology marketing office of the German Aerospace Centre (DLR) provides substantial support to both in-house and external entrepreneurs who want to commercialise DLR technologies. This includes helping with the business plan, finding suitable financing and granting access to existing DLR infrastructure and equipment. ESA business incubation centres provide similar services. With the STAR Exploration Programme, the Korean Aerospace Research Institute supports around ten entrepreneurial projects every year with USD 35 000 granted per project. After project selection, the agency offers consulting and support for the commercialisation phase, as well as monitoring and help with the follow-up stages (Park, 2017[29]).

As the space sector evolves, so does the role of space agencies and that of their technology transfer offices. There is an ever-growing focus on downstream activities and the transfer of space technologies to different sectors. Space agencies' role in technology commercialisation and marketing has in some cases been upgraded from mere brokers to active "helpers" and market makers. Feasibility studies in Canada for a space business incubation centre emphasise the importance of depending on existing organisations for business and commercialisation support, with the space agency keeping responsibility for technology development (Phan, 2017[30]).

With such a variety of TTC objectives, programmes and institutions, it is essential to continue the efforts to identify, monitor, track and, finally, measure the impacts of the transfers of space technologies and their commercialisation in non-space sectors. This is closely aligned with the need for better economic accountability in the sector as a whole. Several agencies already keep track of patent and licensing activities. NASA has witnessed a 293% annual increase in the number of licences released over the last six years (NASA, 2017[31]). On the same line, DLR registered an increase in revenues from licenses from EUR 2.3 million in 2015 to EUR 6.65 million in 2017 (DLR, 2018[32]). Similarly, the Korean Aerospace Research Centre (KARI) has recorded a notable increase in licensing revenues since 2012, accounting for some USD 1.2 million in 2016 (Figure 2.11). The same year, KARI made 23 licensing contracts (Park, 2017[29]).

Figure 2.11. Increase in Korean Aerospace Research Institute (KARI) patents' licensing revenues

Amounts expressed in current USD



Source: Adapted from Park (2017[29]).

The work done by agencies on technology transfers is starting to bear fruit with more returns expected in the coming years. The OECD Space Forum will continue to work with space agencies and technology transfer offices to track developments in space TTC in order to better measure the impacts of space investments on societies and the economy.

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